

Valued forest carbon sinks: How much emissions abatement costs could be reduced in China

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ABSTRACT

Carbon sink is an effective measure to balance the contradiction between economic development and mitigating climate change in China. This paper reveals that environmental performance of forest carbon sinks reflects in economic value by reducing the emissions abatement cost. The carbon trading system is used to demonstrate the environmental and economic value of forests. The forest carbon sequestrations are estimated and predicted in different regions of China. Furthermore, a market model has been established to assess how the emission reduction costs can be reduced among all regions by the year 2030 to achieve the goal of carbon emissions intensity in China. The results show that carbon sequestration trades can reduce the emissions reduction costs and it can represent the value of forest carbon sinks. In particular, when economic growth is maintained in moderate and low level in China, the national carbon trading market with carbon sequestration will decrease the carbon emissions reduction costs more effectively. Besides, carbon sink can bring economic benefits to under-developed regions where there are rich forest resources.

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1. Introduction

Global warming has many adverse impacts on human welfare and social development. To mitigate global warming and reduce greenhouse gas emissions such as carbon dioxide, the development of a low-carbon economy has become more important among all the countries. Economic development is often with pollution and carbon emissions, therefore, there is a contradiction as to develop the economy and at the same time reduce emissions as in the case of China: How can China achieve rapid and steady economic growth? Is it possible for China to achieve the goal of reducing carbon emissions in the process of economic development so as to achieve sustainable development? According to the objectives of the *Paris Agreement*, China will exert greater pressure to achieve emissions reduction targets by 2050. China should attach great importance to low, zero and negative-carbon sources and technologies (Jiang & Green, 2017). The contradiction between environment and economic development has become increasingly

prominent. In order to better balance the relationship between the two, the implementation of climate policies should not affect economic development or even promote it. Carbon emissions reduction and carbon sequestration are two strategies to mitigate climate change, as a result of it, bio-carbon fixation needs to be effectively developed. Forest can fix carbon dioxide but this forest carbon sinks is usually ignored. The study aims to explore the balance between economic development and emissions reduction. The prediction model is constructed in which economic growth rate is used as an influencing factor of forest carbon sequestration while different economic growth scenarios are also set. Meanwhile, China's carbon emissions and the external costs should be explored in order to achieve the minimum social costs as the goal and with consideration of the benefits brought by carbon sinks transactions.

2. Literature review

The issue of global climate change has become the focus of widespread concern in the community. Many scholars have also conducted in-depth analyses in different industries and regions.

From the perspective of carbon emissions, excessive greenhouse gas emissions lead to global warming and environmental problems. Reducing carbon emissions can mitigate the threat of global

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warming and many countries have implemented various policies to reduce this (Zhang and Wang, 2017). Many scholars study the influencing factors of carbon emissions and effective ways of reducing carbon emissions (Ahmad et al., 2016; Lin and Lei, 2015). In addition, studies on carbon emissions reduction help to designate effective emission reduction policies (Sun et al., 2017; Su et al., 2017; Xie et al., 2017). Environmental management innovation is considered as an effective way to solve environmental problems and the design of carbon trading mechanisms are explored (Han et al., 2017a,b; Zeng et al., 2017).

Lin & Jia (2019) argued that China's National Carbon Emissions Trading Scheme (ETS) market is an effective tool to reduce carbon dioxide emissions. Carbon emissions reduction should be paid more attention to in order to mitigate of global warming. The cost of reducing emissions had been calculated by different pathways. The carbon compensation is an important part of the ecological compensation. G. Yang et al. (2019) forecasted the carbon compensation cost based on the theoretical carbon deficit. Social carbon cost was proposed and it measures the damaged economic value caused by the additional carbon missions (P. Yang et al., 2018; Tian et al., 2018). Also, there are some existing studies about exploring carbon price to measure carbon reductions cost and the methods are through China's carbon trading market (Song et al., 2019; Han et al., 2019). Moreover Zhu et al. (2018) analyzed and identified the carbon price drivers by the samples of European Union Emissions Trading System.

In order to alleviate global warming besides the policies of reducing carbon dioxide emissions, bio-carbon fixation can also be used to help reduce the carbon dioxide in the air. Song et al. (2018) proposed that forests may increase carbon dioxide sequestration by about 32% globally. Again Zhang et al. (2018) found the contribution of carbon sinks from forest land to total carbon sinks was greater than ninety percent in China during 1999–2014. Urbanization process and landscape change have an influence on carbon sources and sinks (Han et al., 2017a,b). Afforestation and reforestation activities have a net carbon offset (Yamagata & Alexandrov, 2001; Houghton, 2002).

The role of carbon sinks depends on the international consensus on carbon sink assessment and accounting (Atsushilshii, 2004). Intergovernmental Panel on Climate Change (IPCC) proposed the guidelines for national greenhouse gas inventories and the forest biomass and carbon stock calculation equations are provided (Aalde et al., 2006). Kindermann, McCallum, Fritz and Obersteiner (2008) calculated the forest growing stock, biomass and carbon stock for global 229 countries and territories. Furthermore, forest carbon sequestration should be measured to get the market benefits (Bösch et al., 2017; Ganguly et al., 2018), and the price of carbon will impact on forest carbon stocks and carbon emissions (Guo and Gong, 2017). Therefore when evaluating different ecosystems, the monetary value should be fully taken into account. Hong, Kim & Hur (2018) analyzed the carbon economic effects of sawmill residue from two perspectives of the energy source and base material for products in South Korea. Rehdanz, Tol and Wetzel (2006) conducted a market model to calculate the carbon reductions costs to value carbon sinks with trading among different countries.

Moreover, carbon sequestration stocks and the changes of carbon storage in different regions are predicted (Deng et al., 2017; Salvador et al., 2017). Carbon sequestration in China or some provinces were predicted (Wang et al., 2017; Deng et al., 2017). The Global Forest Products Model (GFPM) was proposed by Buongiorno et al. (2003), it can be used to do the policy analysis and the forest resources is connected with economic development in the model. The GFPM is a research model based on the forest products market and indicators such as forest stock volume under different conditions are predicted by setting different scenarios and assumptions

(Nepal et al., 2013). Raunika, Buongiorno, Turner and Zhu (2010) modified the GFPM and linked the model with different scenarios of Intergovernmental Panel on Climate Change (IPCC) to analyze the wood and forests for the production of bioenergy. The GFPM model had been selected to compare different scenarios and their impact on global bioenergy trade (Matzenberger et al., 2015). Nepal, Ince, Skog & Chang (2012) analyzed and predicted forest biomass and carbon stocks in the United States by setting scenarios for different GDP growth rates in the United States.

Most studies are concentrated on the calculation of carbon sinks volume and the energy saving strategies to realize emissions reduction. Such as that Lin et al. (2012) explored the way of emissions reduction from the perspective of electricity saving potential. There are also some studies which had explored the cost savings obtained from forest carbon sinks in the EU Emissions Trading Scheme (Gren et al., 2012) and how to be beneficial in the New Zealand Emissions Trading Scheme (Diaz-Rainey and Tulloch, 2018). Since Emissions Trading Scheme has just getting started in China, a lot of researches are about the mechanism design and there is a little attention to the value of forest carbon sinks. However, the value of carbon sinks cannot be ignored because of the abundant forest resources in China. Considering the implementation of carbon mitigation policies, it should be simulated at the same time as the establishment of a national carbon sequestration trading market, to compare and analyze the economic benefits of forest carbon sinks whether they are traded or not. This paper tries to calculate the forest carbon sinks volume in china's different regions and reveals that environmental performance of forest carbon sinks reflects in economic value by reducing the emissions abatement cost. The carbon trading system is used to realize the environmental and economic value of forests. The paper is organized as follows: Section 3 uses the GFPM model and sets up scenarios for different GDP growth rates to predict the forest carbon sinks in all the provinces in China, and the carbon trading market model is established to estimate the impact of the transactions of the forest. In section 4, the results of the models are shown. The analysis and discussion based on the estimation results are presented in Section 5. The last section is the conclusions and policy implications.

3. Materials and methods

3.1. Scenarios

Different economic growth rates will have different impacts on forest area changes. Therefore, this paper assumes two different economic growth rates when forecasting forest stock volume. The scenarios are set by following Jiang and Huang (2016). In *China Energy Outlook (2030)*, it is estimated that the average annual growth rate of China's GDP will drop continuously. The economic growth rates in 2016–2020, 2021–2025 and 2026–2030 will stand at 6.8%, 5.5%, and 4.5% respectively. Here, the annual economic growth is set as the first scenario assumption. Lin (2014) claimed that there is a growth potential of 8% in China. Therefore, this paper assumes the growth rate is the second hypothesis of economic development scenario to make a comparison. By comparing the forest volume and carbon storage under the two scenarios, Economic Research Service of United States Department of Agriculture (ERS) predicts average annual growth rate of GDP and per capita GDP,¹ on which the calculation of the average annual growth rate of GDP and per capita GDP in both cases is based, as shown in Table 1.

¹ ERS (Economic Research Service of USDA). International Macroeconomic Data Set. Retrieved from <https://www.ers.usda.gov/data-products/international-macroeconomic-data-set/>.

Table 1
The assumptions of different scenarios.

Years	Scenario I		Scenario II	
	Growth Rate of GDP	Growth Rate of Per Capita GDP	Growth Rate of GDP	Growth Rate of Per Capita GDP
2016–2020	6.8%	6.53%	8%	7.68%
2021–2025	5.5%	5.44%	8%	7.91%
2026–2030	4.5%	4.59%	8%	8.16%

Based on the average of the difference between the real growth rate of GDP and GDP per capita in 31 provinces and the overall growth rate in China from 2003 to 2015, this paper predicts the GDP and per capita GDP of all provinces in 2016–2020, 2021–2025 and 2026–2030. Since the *Forestry Statistical Yearbook* has been counting the forest area and stock volume from 2003, and *China Energy Outlook 2030* sets the goal of national carbon emissions intensity based on 2015, the data interval of this paper is selected from 2003 to 2015.

3.2. Forest volume forecasting model

The current paper aims to explore the relationship between economic growth and forestry carbon sequestration and to predict the forest carbon stocks in different economic development contexts. Joseph Buongiorno and Shushuai zhu's *GFPM 2016* calculates and predicts the future value of forest products, forest reserves, etc., based on data such as forest area, stock volume, yield, etc. Based on the formula in which forest area and stock volume are projected in the future, the model is also used to calculate the amount of forest stock in various provinces in China.

$$I = U * A \quad (1)$$

$$A = (1 + g_a) * A_{-1} \quad (2)$$

$$g_{aa} = (\alpha_0 + \alpha_1 * y) * e^{\alpha_2 * y} \quad (3)$$

$$y = (1 + g_y) * y_{-1} \quad (4)$$

$$g_{ua} = \gamma_0 * \left(\frac{I_{-1}}{A_{-1}} \right)^\sigma \quad (5)$$

The forest volume I is equal to the product of the forest area A and the density U of the forest volume (e.g. the volume of the unit forest area). By calculating and forecasting the forest area and stock volume density, the forest volume is obtained. In Eq. (2), A represents the forest area, A_{-1} is the forest area in the previous year and g_a is the rate of cyclical change in the forest area. The g_{aa} is the rate of change of forest area change rate g_a and y represents the per capita GDP. Per capita GDP can be predicted by equation (3), y_{-1} is the per capita GDP of the previous year and g_y is the rate of change of per capita GDP. The cyclical rate of change in forest stock volume density g_u can be estimated from equation (5), g_{ua} is the rate of change of g_u . I_{-1} is the previous year's forest stock volume. Among these equations $\alpha_0, \alpha_1, \alpha_2, \gamma_0, \sigma$ are the model parameters. In the global forest product model, the designers set the parameters according to the characteristics of forest products of all countries in the world. This paper is to predict the forest volume in various provinces in China. Therefore, it uses the historical data of 31 provinces in China to calculate these parameters. Since the data of forest areas and forest volume in various regions in China before 2003 were largely missing, the time-series data of forest area, forest volume and GDP per capita in China from 2003 to 2015 were used. And all the data

source is *China Statistical Yearbook*.

3.3. Forest carbon stocks measurement model

According to the calculation formula of biochar storage in IPCC2006, the carbon stocks of forestry in 31 provinces in China can be estimated.

$$C = A * V * BCEF * (1 + R) * CF \quad (6)$$

In the above-mentioned equation, A is the area of land remaining in the same land-use category, V is merchantable growing stock volume, R is the ratio of below-ground biomass to above-ground biomass, $BCEF$ is the biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass, and CF is the carbon fraction of dry matter. However, if $BCEF$ values are not available and if the biomass expansion factor (BEF) and D values are separately estimated, the following conversion can be used:

$$BCEF = BEF * D \quad (7)$$

BEF stands for biomass expansion factor, and D is the basic wood densities. $A * V$ represents the total stock volume of the forest. Based on the stock volume forecast model, the total stock volume of the forest in different provinces can be estimated. In addition, the values of BEF (biomass expansion factor), D (basic wood densities), R (ratio of below-ground biomass to above-ground biomass) and CF (carbon fraction of dry matter) are based on the calculation formula of Chinese forest carbon storage in the 2015 *Global Forest Resources Assessment China Report* (FAO, 2015). Based on the report, the related parameters of different tree species are different. All the parameters are calculated by weighted average. Table 2 shows the specific parameters' values.

3.4. Carbon emissions trading model

Rehdanz et al. (2006) proposed an estimation model of emission reductions in different countries. A national carbon trading market is established on the basis of which the value of carbon sinks can be used as offsetting emissions reduction obligation. A simple model of a carbon dioxide emission permits predicts changes in the cost of carbon emission reduction for carbon sequestration transactions in various provinces in China under the objective of reducing carbon dioxide emissions in China by 2030. The model can assess the effect of carbon sequestration on emission reduction and the impact of cost and its allocation.

Table 2
The value of parameters.

Parameters	Value
BEF(Biomass Expansion Factor)	1.35
D(Basic Wood Densities)	0.441
R(Ratio of Below-ground Biomass to Above-ground Biomass)	0.404
CF(Carbon Fraction of Dry Matter)	0.47

The first thing to be taken into consideration is the market for trading allowable emission reductions: Suppose carbon dioxide emission reduction is quadratic, R_i is emission reduction ratio, Y_i is GDP, Q_i presents the volume of emissions trading; P is the price of the emission permit transfer (assuming a perfectly competitive market, different region faces the same price of carbon transfer). E_i is the volume of emission, A_i is the region's capacity for carbon emissions, i represents different regions. If the area emits more gas than the area can hold, it must either reduce its emissions or buy emission permits; α_i represents the parameters. The optimization problem in the area is:

$$\min_{R_i, Q_i} C_i = \alpha_i R_i^2 Y_i + P * Q_i \quad s.t. \quad R_i E_i + Q_i \geq E_i - A_i \quad (8)$$

If the region's emission reduction is less than the region's containable carbon emission, then the target for reducing emission in the region can be sold, for the benefit of $P * R_i E_i$. So the optimization problem in the area is:

$$\min_{R_i, Q_i} C_j = \alpha_j R_j^2 Y_j - P * R_j E_j + P * Q_i \quad s.t. \quad Q_j \geq E_j - A_j \quad (9)$$

At the same time, it is assumed that the total market supply equals the total demand, so it needs to satisfy:

$$\sum_{i=1}^I Q_i + \sum_{j=1}^J Q_j - \sum_{j=1}^J R_j E_j = 0 \quad (10)$$

The parameters are defined as:

$$\alpha_i = 1.57 - 0.17 \sqrt{\frac{E_i}{Y_i} - \min_i \frac{E_i}{Y_i}} \quad (11)$$

The parameter represents that regions which emit a lot of carbon relative to their production, have low emission reduction costs. It means the carbon emissions reductions costs are expensive for the regions where the emission intensity is low (Tol, 2004; [Rehdanz et al., 2006](#)).

4. Results

4.1. Forest carbon sinks

According to the projected results of forest carbon stocks under different economic growth rates in China's different regions, estimations are obtained by the forest carbon stocks measurement model. At the same time, the amount of forest carbon sequestration can be calculated based on the difference in forest carbon stocks between 2015 and 2030. Results are shown in [Table 3](#).

Based on the results above, it can be found that there are three relationships between the economic growth rate and forest carbon stock. The higher economic growth and the higher forest carbon sinks in some regions based on the results, such as Inner Mongolia, Jilin, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Guizhou, Yunnan, Tibet, Ningxia and Xinjiang. Results with high economic growth rate are the lower than lower economic growth rate which is only in Liaoning. And there are also some regions with the economic growth rate that has no effect on forest carbon stocks and carbon sinks. In order to verify the results, this paper explores the relationships between the forest area or forest volume density and GDP by using 31 provinces panel data.

Forest volume is the product of the forest area and volume density. According to the results in [Table 4](#), the relationship between forest volume and GDP can be obtained from the function.

$$\widehat{\text{Forest volume}} = 0.43 * 10^{-6} * \text{GDP}^2 - 0.3033 * \text{GDP} + 43099.71$$

From the structure of the function, it can be found that GDP has a significant negative impact on forest volume, and its squared term is positive. According to the form of the function, it can be found that there is a U-shaped curve which represents the relationship between the forest volume and GDP. The shape is contrary to the environmental Kuznets curve but the relationship between environment and economy is the same. The forest would be lost and develop other high value-added industries in order to the development of the economy. When the economy develops to a certain level, the importance of environmental protection is noticed. Hence the amount of forest volume increases as the economy grows. Based on the shape of the curve, there are two kinds of relationship between forest volume and GDP. When GDP is lower than the threshold, GDP has a negative impact on forest volume. As GDP is more than the threshold, the relationship is the contrary. The results in [Table 3](#) is projected with high or low economic growth rate, GDP is higher than the threshold in most regions. Therefore forest volume predicted at a high rate of economic growth is higher than that in the case of lower economic growth. Meanwhile, GDP is lower than a threshold in Liaoning. There are also some regions' forest volume has no difference at two level economic growth rate. Since the coefficients of GDP and its squared term are small and the signs are contrary. GDP has little impact on the forest volume.

For most of the areas, forest volume at a high rate of economic growth is higher than that of lower economic growth. The possible reasons are the demand for forest products, which increases in the higher economic growth rate in these areas, and the lower cost of afforestation, which promotes the development of forestry. In other regions, the rate of economic growth does not affect the amount of forest stock. This is mainly because forestry is a relatively small industry in the economic society and the roughly identical forecast results of forest area are under the two scenarios. The economy developed rapidly and the rate of economic growth has little effect on forest areas in these regions.

4.2. Valued carbon sinks

According to *China's Energy Outlook 2030*, by 2030 Chinese carbon intensity will be reduced to about half of that of 2015. According to the carbon emissions intensity of provinces in China in 2015 which is calculated from the relevant data of *China Energy Statistical Yearbook*, the carbon intensity in different regions in 2030 are predicted. Then the carbon emissions of 31 provinces and municipalities in China in 2030 are calculated according to the two scenario assumptions of Chinese GDP growth rate. Carbon emissions in Tibet are based on findings from the CEADs team ([Shan et al., 2017](#)). Putting the above forecast for forestry carbon sequestration in 31 provinces into the model, the calculated results are divided into eight cases.

According to the assumptions of the scenarios above, the relevant data of carbon sinks, economic development and other indicators of China's provinces are brought into the carbon market model for calculation. When there is no carbon sequestration trading market, the price of carbon dioxide emission is zero, and there are no trading events. When the carbon sequestration in the area is larger than the amount of emission reduction that needs to be done locally, the cost of abatement in the area is zero. [Table 5](#) shows the calculation results of carbon dioxide emission reduction costs in each of the 8 different scenarios.

Table 3

Results of forest carbon stocks and sequestration in 2030.

Area	Forest carbon stocks in 2015 (Million tons)	Forest carbon stocks in 2030 (Million tons)		Forest carbon sequestration from 2016 to 2030 (Million tons)	
		Scenario I	Scenario II	Scenario I	Scenario II
Beijing	6.5666	15.0338	15.0338	8.4672	8.4672
Tianjin	1.7232	2.3842	2.3842	0.6610	0.6610
Shanxi	44.8687	72.5370	72.5370	27.6682	27.6682
Inner Mongolia	619.7905	1077.8882	1170.1437(↑)	458.0977	550.3531(↑)
Liaoning	115.3899	157.2695	153.9390(↓)	41.8797	38.5491(↓)
Jilin	425.0356	441.2520	459.6356(↑)	16.2164	34.6000(↑)
Heilongjiang	757.8022	867.1759	867.1759	109.3737	109.3737
Shanghai	0.8585	3.7766	3.7937(↑)	2.9180	2.9352(↑)
Jiangsu	29.8077	149.3158	149.3158	119.5081	119.5081
Zhejiang	99.8800	131.0182	131.0372(↑)	31.1382	31.1572(↑)
Anhui	83.2720	159.8179	159.8179	76.5459	76.5459
Fujian	280.0918	344.1046	358.3100(↑)	64.0128	78.2183(↑)
Jiangxi	188.1554	224.5136	224.5136	36.3582	36.3583
Shandong	41.0940	67.8749	67.8749	26.7808	26.7808
Henan	78.7557	235.4624	235.4624	156.7067	156.7067
Hubei	132.0061	274.2066	274.2066	142.2006	142.2006
Hunan	152.4905	197.8908	197.8909	45.4004	45.4004
Guangdong	164.3925	178.0801	192.4510(↑)	13.6876	28.0585(↑)
Guangxi	234.6691	436.8383	437.2322(↑)	202.1692	202.5631(↑)
Hainan	41.0205	61.9988	61.9988	20.9783	20.9783
Chongqing	67.5016	104.0769	104.0769	36.5753	36.5753
Sichuan	773.9869	1047.0593	1047.0593	273.0724	273.0724
Guizhou	138.5640	284.4175	285.9198(↑)	145.8535	147.3557(↑)
Yunnan	780.0183	967.8524	1154.5223(↑)	187.8341	374.5040(↑)
Tibet	1042.1504	1892.5833	2150.1770(↑)	850.4330	1108.0266(↑)
Shaanxi	182.4053	287.8745	287.8745	105.4692	105.4692
Gansu	98.8398	240.5473	240.5473	141.7075	141.7075
Qinghai	19.9542	488.8543	488.8543	468.9001	468.9001
Ningxia	3.0422	3.4982	5.7012(↑)	0.4560	2.6590(↑)
Hebei	49.6409	83.4589	83.4589	33.8180	33.8180
Xinjiang	155.0465	156.9249	176.7876(↑)	1.8784	21.7411(↑)

Note: The symbol “↑” represents that results at a high rate of economic growth is higher than that in the case of lower economic growth and the symbol “↓” represents that results at a high rate of economic growth is lower.

Table 4

The coefficients of regressions.

Dependent variable	Forest area	Forest volume density
GDP	−0.0039479***	−0.000108*
Constant	771.402***	55.87192***

Note: * Significant on 10%.

** Significant on 5%.

*** Significant on 1%.

5. Discussion

5.1. How much emissions abatement cost is reduced by forest carbon sinks?

According to the results of no carbon trading market, the carbon emissions abatement costs with consideration of forest carbon sinks is about 34% of costs without forest carbon sinks when the GDP growth rate is lower. Meanwhile the ratio of two abatement costs is 45% under higher GDP growth rate. It can be found that forest carbon sinks reduce the emissions abatement costs effectively. As shown in Fig. 1 and Fig. 2, it can be seen that the emissions reduction cost is obviously lower than that of the non-carbon sinks without a national carbon trading market in China's different regions. When the GDP growth rate is lower, Jiangsu and Sichuan province get more to reduce emissions reduction costs under the situations of holding carbon sinks. It also shows that Jiangsu, Sichuan, Henan, and Hubei province reduce more costs with carbon sinks when the growth rate is high in China.

Overall, by 2030 it has been predicted that the national carbon

sequestration in the forest during 2016–2030 will account for about 97% of the national total amount of carbon dioxide emissions, given the economic slowdown. Under the economic growth rate of 8%, the forest carbon sequestration accounts for 73.7%. Carbon dioxide fixed in forests can effectively reduce the emission reduction costs in all the provinces. The reduction in abatement costs can be considered as the value of forest carbon sinks. Forest is a huge carbon pump, and forest carbon sinks is another way to achieve the goal of emissions reduction and there is an assumption that the forest carbon sinks have no cost. Hence adding forest carbon sinks will have a great impact on the cost of reducing emissions in all provinces. Due to the fact that the carbon sequestration of marine organisms does not yet have a unified measurement standard, the current paper only estimates the forest carbon sinks at present. Therefore, the effect of marine carbon sinks is ignored, it can be expected that the addition of marine carbon sinks can reduce the cost of carbon dioxide emissions reduction in the coastal areas.

5.2. How much the value of forest carbon sinks is realized in the carbon trading market?

Moreover, comparative analysis is carried out from the perspective of whether to develop carbon sinks or not. First, in the absence of a national carbon trading market, the inclusion of forest carbon sequestration into local carbon stocks will help to reduce the local cost of carbon emissions reduction abatement. However, in some areas where the carbon stock is larger than the carbon emissions reduction, the corresponding economic benefits are hardly obtained, the effect of reducing costs is less obvious than the effect of existing market transactions.

Table 5
Carbon dioxide emission reduction costs in China.

Area	No carbon sequestration trading market				Carbon sequestration trading market			
	Scenario I		Scenario II		Scenario I		Scenario II	
	No carbon sinks	Forest carbon sinks	No carbon sinks	Forest carbon sinks	No carbon sinks	Forest carbon sinks	No carbon sinks	Forest carbon sinks
Scenarios	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Beijing	108964.12	32609.80	136076.82	74408.76	17204.66	286.34	25096.89	5033.70
Tianjin	116590.99	114352.46	144762.90	142824.08	56499.89	1896.51	68829.51	20066.18
Shanxi	55222.06	33931.12	69037.47	54337.07	54490.24	2765.34	55595.16	36473.59
Inner Mongolia	146623.31	1887.22	181642.61	9743.94	76562.98	1286.15	116249.45	3284.91
Liaoning	155678.35	73165.26	194016.28	129564.78	101580.95	2539.06	133395.13	34123.17
Jilin	87131.52	57302.81	108382.91	57726.08	62842.04	1933.07	79010.58	18199.11
Heilongjiang	54549.59	0.00	68384.87	0.00	12798.02	−2670.08	29568.19	−14739.52
Shanghai	87957.86	32775.32	110327.17	86792.58	7049.16	128.37	20064.92	4838.56
Jiangsu	408322.88	117762.98	508373.98	247436.10	210153.51	3856.61	270175.12	55280.47
Zhejiang	194459.63	52845.39	242991.17	131475.93	57433.53	947.56	86216.61	17823.08
Anhui	147560.49	47719.24	183341.73	90780.76	121166.94	2788.93	149707.26	34604.95
Fujian	163208.49	4421.82	202980.38	19957.25	65263.62	346.86	81941.18	6888.38
Jiangxi	112804.30	47467.66	140147.45	80603.87	77491.88	1866.39	95515.35	22486.10
Shandong	317214.18	255113.94	395763.27	347980.56	200075.35	6483.31	271950.49	80592.65
Henan	192546.60	392.81	240110.91	40660.88	125310.45	180.48	167478.80	20000.43
Hubei	225697.60	21388.93	279910.33	72327.93	154122.59	1737.86	185508.95	27939.10
Hunan	213614.12	117602.06	265048.79	177369.45	135474.47	3633.37	163815.56	40833.32
Guangdong	333768.97	229864.18	417008.73	270457.23	72765.14	1869.98	108770.36	24173.06
Guangxi	117376.68	0.00	145756.06	0.00	73391.18	−3026.45	89729.30	−15530.35
Hainan	24042.22	0.00	29886.50	571.94	13265.23	−126.35	16492.46	492.58
Chongqing	122067.29	45645.10	151352.83	79129.53	73648.93	1601.53	88204.88	19043.10
Sichuan	198166.08	0.00	246282.46	0.00	112672.54	−3706.47	139535.59	−15986.89
Guizhou	101260.39	29052.49	125166.75	53264.96	77138.65	4526.03	107652.77	42629.47
Yunnan	84905.13	0.00	105604.03	0.00	62186.94	−2891.31	78055.13	−54421.24
Tibet	6805.36	0.00	8457.67	0.00	18.47	−23863.64	22.81	−236136.90
Shaanxi	144655.51	0.00	179281.89	0.00	11847.34	−2606.06	14637.56	−18573.27
Gansu	35934.87	7620.30	44798.87	16808.40	−189743.65	3013.01	−194794.29	13840.25
Qinghai	18583.23	0.00	23041.80	0.00	18300.51	−11917.27	21829.11	−87455.45
Ningxia	24901.62	24749.42	30830.67	29963.81	−36880.99	3595.54	−35948.35	26467.91
Hebei	122217.43	15799.04	152957.82	43717.10	45431.98	528.37	53287.70	7887.39
Xinjiang	51280.17	50166.68	63874.45	56322.33	32173.00	4662.18	−38344.96	48754.98
Total	4174111.05	1413636.02	5195599.56	2314225.31	1901735.54	1665.23	2449249.24	168912.83

Note: The negative sign represents profit.
Unit is 100 million yuan.

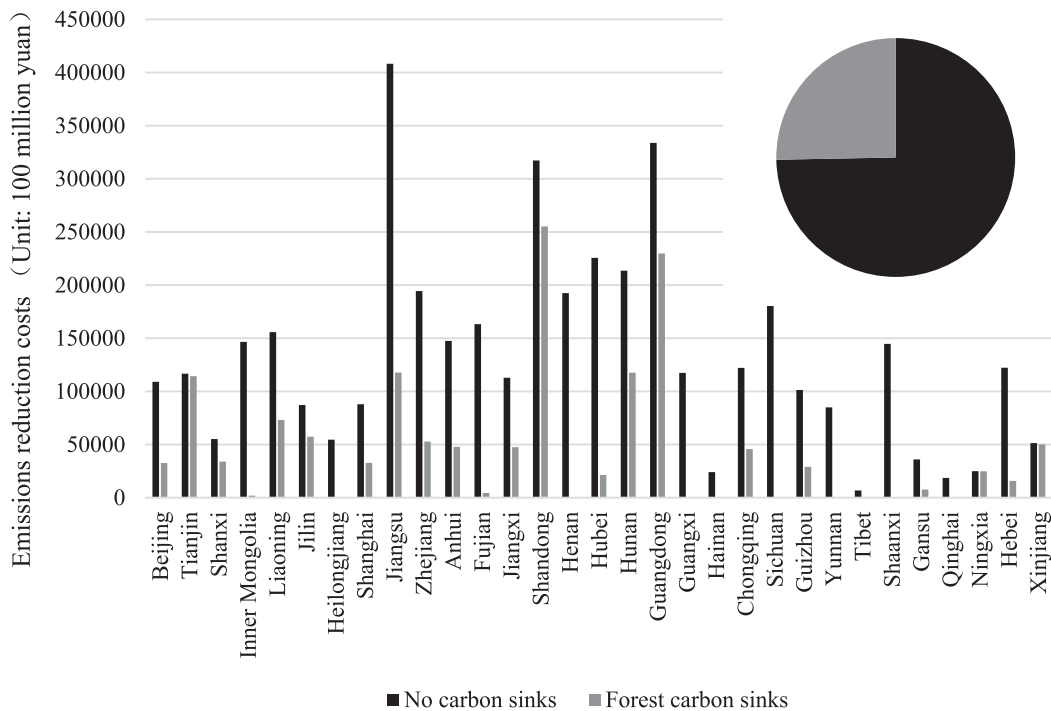


Fig. 1. Emissions reduction costs under lower growth rate.

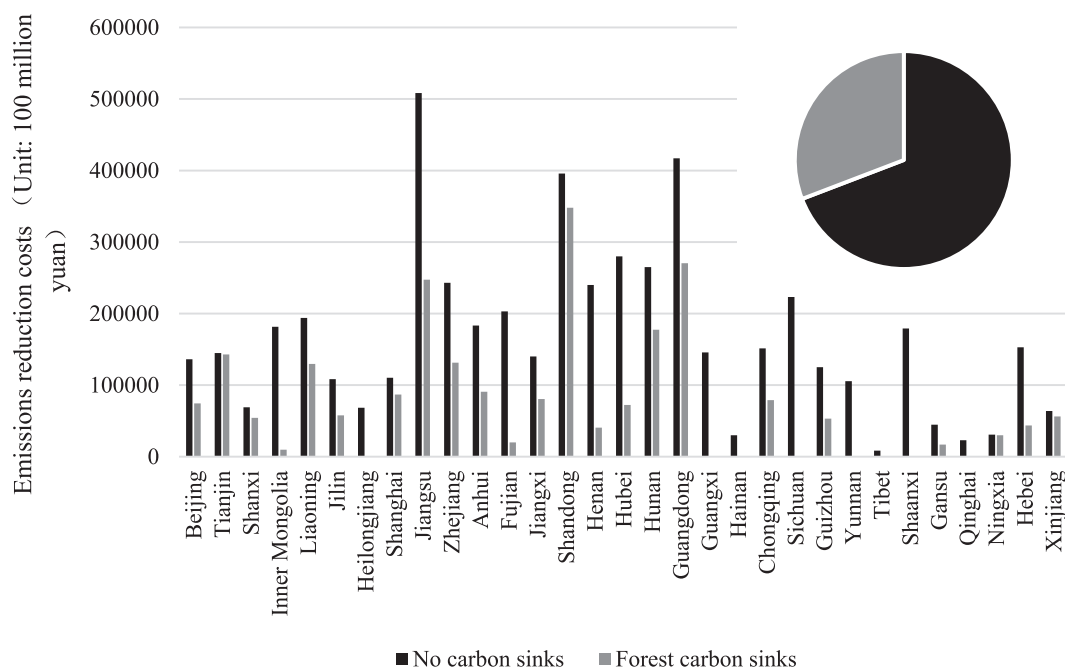


Fig. 2. Emissions reduction costs under higher growth rate.

The second issue is the existence of a national carbon trading market as shown in Fig. 3. When the local forest carbon sequestration is used to offset the local carbon emissions, the reduction of the national emissions reduction costs is obvious. Under the circumstances of lower economic growth rate, economic surpluses are realized in Heilongjiang, Guangxi, Hainan, Sichuan, Yunnan, Tibet, Shaanxi and Qinghai provinces as the conclusion is shown in Table 6. Economic surpluses have been realized in Heilongjiang, Guangxi, Sichuan, Yunnan, Tibet, Shaanxi and Qinghai provinces under the circumstances of higher economic growth rate. These provinces have large reserves of forest carbon and many of them are with stunted economic development. Developing forest carbon sinks and integrating them into the national carbon trading market will, to some extent, contribute to the economic development in these regions. Whereas, the value of forest carbon sinks can balance China's economic development between different regions and regional environmental pollution, carbon dioxide emission, and other issues among the contradictions.

5.3. How economic growth affects the value of forest carbon sinks

Based on the result which is showed in Table 5, the emissions abatement cost with forest carbon sinks under a lower GDP growth rate is account for 61% of it under a high GDP growth rate. And the cost reduced by forest carbon sinks with a lower growth rate is about 96% of it with a higher growth rate. Meanwhile, when there is a national carbon trading market, the ratios are about 1% and 83% respectively. It can be found the lower economic growth help forest carbon sinks to achieve their economic value. Moreover, the importance of economic growth is more effective when there is a carbon trading market. When the GDP growth rate is set lower in China, the forecast of forest area will be lower than that of the higher growth rate. Therefore, the forest carbon stocks are also lower than those with a higher growth rate. Forestry development is a part of the regional economic development. When the GDP growth rate is set higher, it can also promote the development of

the forestry system. Hence the number of trees increases, it can increase the forest carbon reserve. However, in the case of rapid economic development, carbon dioxide emissions will be higher than that of the slower economic development. Under the influence of more carbon dioxide emissions, the cost of reducing carbon dioxide emissions is higher than that of lower economic growth rate under the circumstances of a higher economic growth rate. Considering the environmental cost, the economic growth rate in the future should be rationally set to achieve sustainable economic development.

5.4. What is the importance of the national carbon trading market?

From the point of view as to whether getting carbon emissions trading or not to conduct a comparative analysis, it is found that when all the provinces across the country are allowed to trade carbon emissions permits, the cost of reducing carbon emissions in the country will be reduced under the four different conditions. As shown in Fig. 4, the difference in emissions reduction costs of emissions permits transactions among China's different regions between all the four scenarios is positive. Thus, the establishment of a national carbon trading market in China is conducive to economic development, and some economically backward regions will obtain certain economic benefits. Due to the relatively backward economic development, coupled with the superior resource and environment, there is a large space for carbon emissions in these economically backward regions. When carbon sequestration trading appears on the national market scale, it can effectively utilize local resources and promote the economic development of these regions. Additionally, it is found that when there is a emissions trading market, the impact of economic growth rate on the reduction cost of all the regions is far less than that in the two scenarios. In other words, there is no carbon sink in the area, the market can effectively reduce the impact of the economic growth rate on the cost of reducing carbon dioxide in the regions.

Furthermore, with the existence of a national carbon

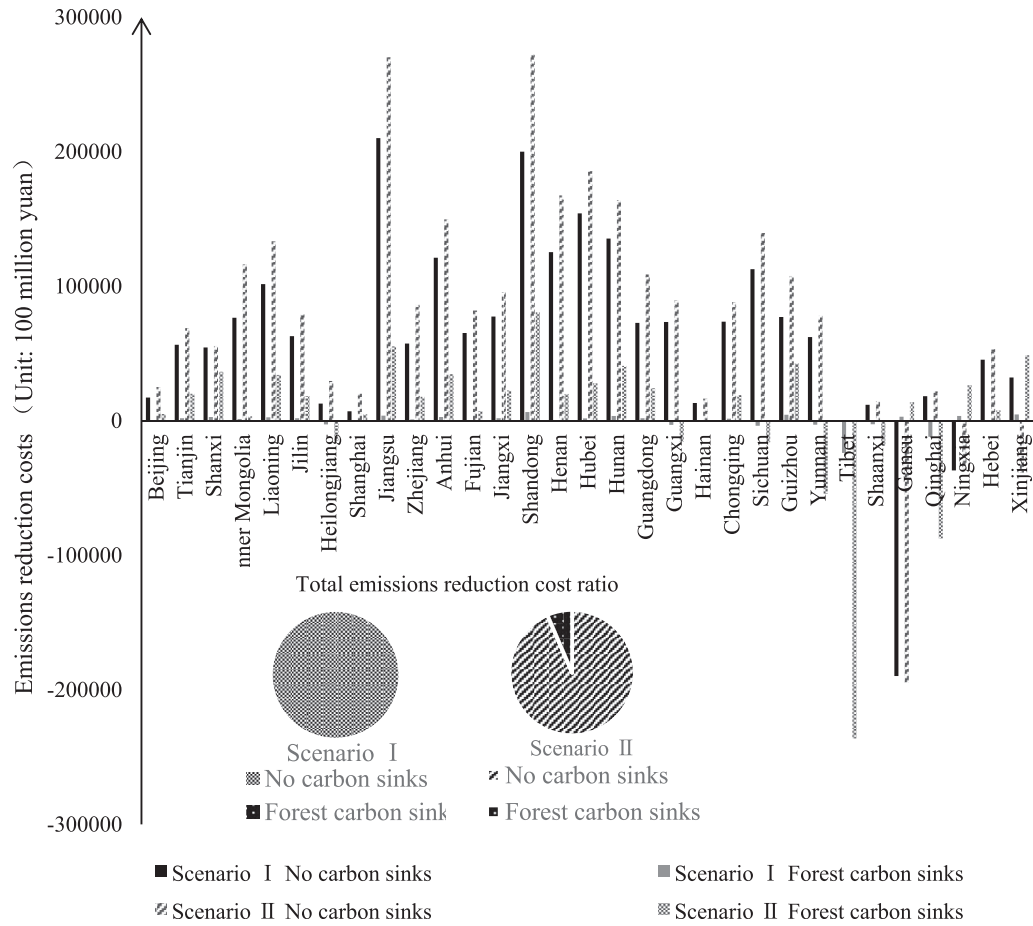


Fig. 3. Emissions reduction costs with carbon emissions trading.

sequestration trading market, all the regions achieve lower emissions reduction costs in the absence of carbon sinks. Some provinces realized the surplus without any carbon sinks that are shown in Table 6, such as Gansu, Ningxia, and Xinjiang which is under the situation of higher GDP growth rate. This indicates that in the case of carbon dioxide emissions permits trading, selling the carbon right for certain economic benefits can be realized with lower local treatment costs of carbon dioxide emissions.

6. Conclusions and policy implications

Abundant carbon sink resources can offset some part of

emissions reduction obligations in some regions, thereby reducing carbon emissions reduction costs. When the economic growth is more rapid, there will be more carbon emissions. Carbon sinks reduce fewer carbon emissions reduction costs than it is in the lower economic growth rate. As a result of it, the government should maintain a moderate and low economic growth rate to make the country develop sustainability. In China, regional economic development is uneven. National carbon trading market can give the advantages of resources to economically backward areas and promote regional economic development, then it can ease the unbalanced economic development among different regions in China. Regions with rapid economic development will generate

Table 6
Provinces that receive benefits from carbon trading market.

Area	Scenario I		Scenario II	
	No carbon sinks	Forest carbon sinks	No carbon sinks	Forest carbon sinks
Heilongjiang		✓		✓
Guangxi		✓		✓
Hainan		✓		✓
Sichuan		✓		✓
Yunnan		✓		✓
Tibet		✓		✓
Shaanxi		✓		✓
Gansu	✓		✓	
Qinghai		✓		✓
Ningxia	✓		✓	
Xinjiang			✓	

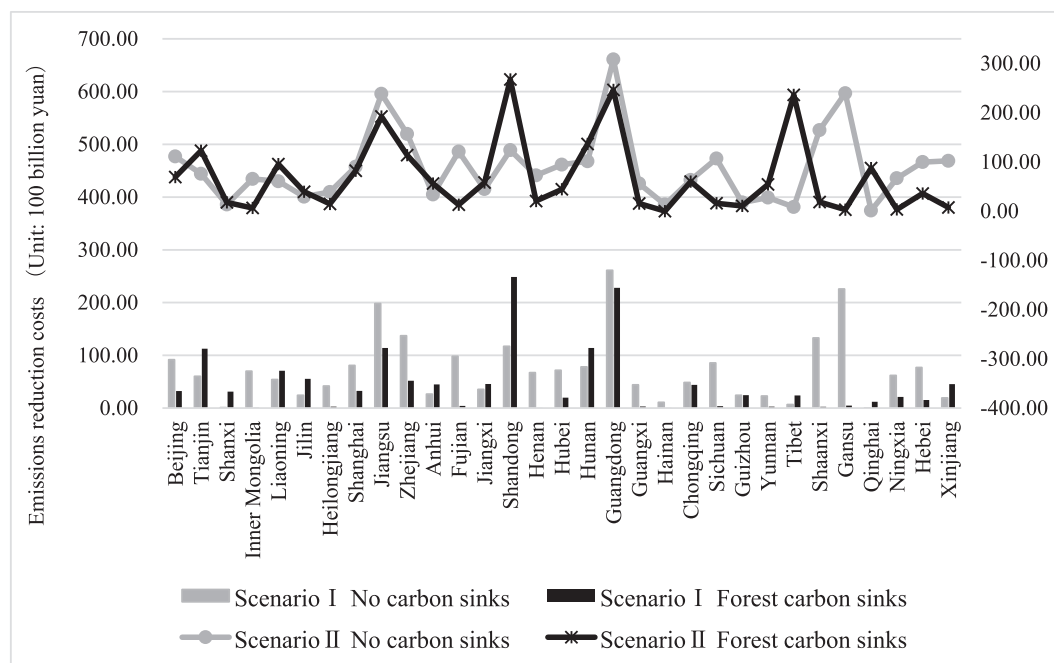


Fig. 4. The difference of abatement costs between with and without market.

high carbon emissions. When there is a national carbon trading market, it will increase the cost of regional carbon emissions due to the purchase of carbon emission rights. It will encourage them to implement the measures of energy saving and emissions reduction. The trading of carbon emissions rights can promote the transfer of income from the more economically developed regions to the more backward regions. And it also can realize the value of forests as carbon sinks effectively.

The development of forest carbon sinks will affect climate policy, increasing the volume of sinks, which can reduce the pressure of emissions reduction. But it cannot fully achieve carbon emission reductions. Some regions can increase the number of carbon sinks planting as a supplementary strategy while implementing carbon emissions reduction policies.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2019.03.221>.

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